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SMITH et al.
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Filed: June 1, 2000
For: GAS FLOW MEASUREMENT DEVICE

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August 6, 2003

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Sir:

SUBMISSION OF PRIORITY DOCUMENTS

It is respectfully requested that this application be given the benefit of the foreign filing date under the provisions of 35 U.S.C. §119 of the following, a certified copy of which is submitted herewith:

Application No.	Country of Origin	Filed
PQ0943	Australia	June 11, 1999

Respectfully submitted,

NIXON & VANDERHYE P.C.

By: [signature]
Paul T. Bowen
Reg. No. 38,009

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AUSTRALIA

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I, JONNE YABSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PQ 0943 for a patent by RESMED LIMITED as filed on 11 June 1999.

WITNESS my hand this
Fifth day of June 2003

J R Yabsley

JONNE YABSLEY
TEAM LEADER EXAMINATION
SUPPORT AND SALES

S & F Ref: 442600

ORIGINAL

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION FOR THE INVENTION ENTITLED:

Gas Flow Measurement Device

Name and Address of Applicant: ResMed Limited, an Australian company, ACN 003 765 142, of 82-84 Waterloo Road, North Ryde, New South Wales, 2113, AUSTRALIA

Names of Inventors: Ian Malcolm Smith, Peter John Deacon Wickham and Shaun Law.

This invention is best described in the following statement:

5805

GAS FLOW MEASUREMENT DEVICE

Field of the Invention

The present invention relates to a device for measuring the volumetric flow rate of a gas through a conduit, and in particular for measuring breathable gas flow associated with a continuous positive airway pressure (CPAP) apparatus, ventilatory assist device, or the like.

Definition of Terms

The term 'conduit', used herein, is to be understood in a non-limiting sense. Particularly, it is not limited to a flexible air hose that interconnects a flow generator with a patient mask for CPAP or assisted ventilation equipment.

In this specification, the phrases 'encode', encoder' or encoded' are to be understood as meaning any apparatus or operation that effects the degree of received light transmitted as a function of another variable, such as displacement.

Background of the Invention

Measurement of the volumetric flowrate of gas ("flow") in CPAP or ventilatory assistance devices is required for calculating ventilation, and to detect changes between the inspiratory and expiratory phases of breathing. It is very important that flow be determined accurately.

Typically, fixed or variable orifice meters are used to determine flow. In these meters, a pressure transducer measures the pressure differential across a fixed or variable orifice. Problems with orifice meters include high pressure drop, poor gain and poor linearity at low flows. There are similar problems when the direction of flow is reversed.

Another known device is the moving vane flow meter. In these meters, movement of the vane varies an inductive or capacitive signal. Problems with moving vane transducers include poor dynamic response and limited bandwidth. A further

disadvantage of the moving vane transducer is that variations in ambient air temperature and air density can result in errors. This is because the vane transducer inherently measures air mass, rather than air volume.

More sophisticated devices such as thermal flow meters (which measure the molecular flow of gas) and turbine type devices may be too large and expensive for applications in the stated field.

It is an object of the invention to overcome or at least ameliorate one or more of the disadvantages of the prior art.

Summary of the Invention

The invention discloses a measuring device for determining gas flow through a conduit, said device comprising:

a vane arrangement extending into the conduit to be displaceable under the influence of gas flow in the conduit;

a light source arranged to provide a uniform intensity of light over a range of displacement of the vane arrangement;

an optical encoder interposed between the light source and the vane arrangement effective over the range of displacement to encode the light source as a function of displacement of the vane arrangement under the influence of gas flow; and

a light detector, arranged to optically communicate with the encoded light source and provide an output signal related to gas flow.

In one form, the vane arrangement forms at least one light guide, and the encoder is interposed between a free end of the light guide and the light source so that the encoded light is optically communicated to the light guide. In another form, the vane arrangement has two light guides, and the encoder has two rows of regularly spaced discrete light sources aligned with a free end of the respective light guide. In a further form, the vane arrangement carries a first polarising element, and the first polarising element and a second, fixed polarising element form the encoder. The light source, first and second polarising elements and the light detector are in optical alignment, with

the planes of polarisation of the respective first and second polarising elements interacting as a function of displacement of the vane element to result in variable optical transmitivity.

The invention further discloses a method for determining gas flow through a conduit, comprising the steps of:

providing a uniform light source;

encoding the light source in a manner that is a function of a displacement of a vane arrangement located within the conduit and under the influence of gas flow; and

detecting the encoded light and producing an output signal related to gas flow.

Advantages given by a measuring device embodying the invention over prior art flow meters include:

(1) It has a good dynamic response due to the low inertia of the vane and fast electrical response of the light detector.

(2) There is a low pressure drop across the vane due to the narrow width and small area.

(3) It is simple to construct.

(4) It has a theoretical infinite resolution when using an analogue electrical signal.

(5) It has one-point calibration at zero flow point, for zero flow DC signal.

(6) It has automatic calibration during start-up to correct for air density, relative humidity and temperature.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a perspective view of a longitudinal cross-section of a conduit, fitted with first form of flow sensor;

Fig. 2 is a flattened plan view of a mask used in the flow sensor of Fig. 1;

Fig. 3 is a longitudinal cross-section of a conduit, fitted with a second form of flow sensor;

Fig. 4 is a longitudinal cross-section of a conduit, fitted with a third form of flow sensor;

Fig. 5 is a transverse cross-section of the conduit and flow sensor of Fig. 1;

Fig. 6 is a perspective view of a longitudinal cross-section of a conduit, fitted with a fourth form of flow sensor;

Fig. 7 is a timing diagram used in the embodiment of Fig. 6;

Figs. 8a and 8b are schematic diagrams of a fifth form of a flow sensor, having a digital encoder and circular section flexible light guides;

Figs. 9a-9d are schematic diagrams of a sixth form of flow sensor, using polarising films;

Fig. 10 is a graph showing the relation between sensor output voltage versus flow;

Fig. 11 is a graph comparing the experimental output/flow characteristics for a set of measurements and theoretical calculations; and

Fig. 12 is a schematic diagram of CPAP or assisted ventilation apparatus incorporating a flow sensor.

Detailed Description of the Preferred Embodiments

Referring to Fig. 1, there is shown a flow sensor 10 arranged inside a conduit 12 associated with a CPAP apparatus, ventilatory assist device, or the like. The conduit 12 provides a path for breathable gas to flow, in either direction denoted by reference numeral 11. The flow sensor can be positioned in the air conduit, near the patient mask or generally at some position downstream of the blower.

The flow sensor 10 includes a "light-pipe" vane 14, an arcuate portion 13 and a light detector 20. The vane 14 is formed from a very light polymer such as acrylic that is optically transparent. The shape of the vane 14 can be other than shown in Fig. 1, as will be later discussed in relation to Fig. 5.

The vane 14 extends from an attachment end 19 formed in a wall portion of the conduit 12 such that a free end 18 of the vane 14 is able to swing substantially throughout a range extending over the arcuate portion 13 in response to gas flow through the conduit 12. A constant radial distance is maintained between an upper plane 9 of the arcuate portion 13 and a polished end surface 8 of the free end 18 during a full range of normal movement of the vane 14.

When light from a uniform light source 16 reaches the arcuate portion 13, subject to the influence of an encoder in the form of a mask 24 located on the arcuate portion 13, the polished end surface 8 of the free end 18 receives and transmits light in a lengthwise direction 15 through the length of the vane 14. The relationship of gas flow to radial displacement of the vane 14 though the arcuate portion 13 is typically non-linear. This non-linearity can be compensated, if necessary, by adopting a mask shape 24' having the aperture 26 shown in Fig. 2. Alternatively, this non-linear characteristic can be compensated for in post detection processing.

The attachment end 19 of the vane 14 is in optical contact with a detection face 22 of the light detector 20. The light detector 20 provides an electrical output signal at the pins 23 according to an intensity of light received on the detection face 22 which has travelled in direction 15 discussed above. A suitable detector is the Honeywell phototransmitter #SD3443, used in its linear range. The intensity of light received on the detection face 22 corresponds to the position of the polished end surface 8 of the vane 14 in relation to the arcuate portion 13, by virtue of the variation of light source intensity transmitted through the mask 24, 24'.

The flow sensor 10 can be used to determine gas flow direction by virtue of the smallest aperture/minimum detected voltage output at pins 23, occurring at a maximum flow position of the vane 14 in a first direction. A largest aperture/maximum detected voltage output at pins 23 occurs at the maximum flow position of the vane 14 in a second, opposite direction. Zero gas flow therefore occurs when a voltage output at pin 23 equals a mid-voltage value between the maximum and minimum values.

The light source 16 is desirably of uniform intensity across the range of the aperture 26 of the mask 24 which communicates with a polished end surface of the free end 18. This uniformity of the light source 16 can be achieved in various ways, as will now be discussed.

Referring to Fig. 3, which is a cross-sectional view of the flow sensor 10, the light source 16 can be an electro-luminescent film (e.g., Seikosha EL film) formed into the required curved shape and be directly laminated on a back face of the mask 24. An alternative can be an LED back lit panel.

A further alternative arrangement for achieving a uniform light source is shown in Fig. 4, where a light diffuser 30 is placed between a lamp 31 (or lamps) provided externally to the arcuate portion 13.

The mask 24, serving as an analogue intensity encoder, can be manufactured in various ways, including a photographically produced opaque outline onto translucent glass or polymer, or laser cut/chemically etched thin metal film. It can also be integral of the arcuate portion 13, for example, as an injection moulded part.

Referring to Fig. 5, another form of vane 25 is shown in transverse cross-section with respect to a conduit 26. A housing 32 extends from the conduit, in which the light source 16 is located. The free end 27 of the vane 25 is generally wider than an attachment end 28, so as to provide a maximum bending angle of the vane 25 throughout the arcuate portion 13, for a given surface area of the vane 25 presented to gas flow in the conduit 26. This minimisation of the surface area of the upper portion of the vane 25 minimises gas flow restriction, inertia and pressure losses that are usually associated with prior art vane sensors.

The light transmission path 29 of the vane 25 is an optical fibre of flattened rectangular cross-section. Typically, there will be minimal light entering the vane 25 through the side walls, due to the small angles of incidence to those surfaces which (obeying Snell's law) results mostly in external reflection from the surfaces. However, if otherwise necessary, the entire vane 25, except for the polished end, can be coated with opaque material.

A yet further form of flow sensor will now be described with reference to Figs. 6 and 7. Here, the varying aperture (analogue) encoding mask 24 of Fig. 5 is replaced with a 'digital' encoder in the form of having two rows (channels) of slots 44, 45, each row being parallel to the gas flow direction 11 as shown. The vane 41 is split into two separate light pipes 46, 47, each of which corresponds to one of the two provided rows of slots 44, 45 of the mask 40. A pair of light detectors (not shown) are also provided, each of which correspond to a single row of slots 44, 45 and its associated light guide 46, 47.

When the vane 41 is displaced in response to gas flow through the conduit, the amplitude of the light received for each of the two channels is detected as pulses which can be processed as digital signals. An example of a suitable detector is Honeywell Optoschmitt detector #SD5620-1. Similar to the arrangement shown in Fig. 1, a light detector is placed at the receiving attachment end of each of the two channels.

By spacing the two channels 90 degrees (electrical) apart, as shown in Fig. 7, (in the direction of vane movement) the directions of motion can be determined by the unique combination of paired outputs of the digital state of each of the detectors in channels A & B. For example, movement of the light guides in one direction may result in an output of: (1,1) (1,0), (0,0), (0,1) (1,1). Movement in the reverse direction may result in the following output: (1,1), (0,1), (0,0), (1,0) and (1,1). These two patterns are distinct and hence flow direction can be determined.

The quantity 360 electrical degrees is the distance between corresponding slots, equivalent to the distance between successive rising edges of the resultant electrical pulses. Therefore, 90 electrical degrees is equivalent to 1/4 wavelength.

The value of flow is determined by the absolute number of output pulses counted, relative to the zero count (i.e. flow generator off). Changes in flow are determined by incremental changes in encoder output.

The encoder type mask 40 can be manufactured using the same processes as that described earlier for the analogue mask.

Further, the vane movement versus flow relationship can be linearised by either spacing the slots in a non-linear pre-determined pattern, or linearised in post- detection processing. The "home" or indexed position of the encoder is defined during machine start-up as being zero pulses at zero flow.

A principal advantage of the embodiment of Figs. 6 and 7 is that a digital TTL/LSTTL/CMOS compatible output can be provided for direct interfacing to digital circuitry. This usually results in a more stable output and a reduction in parts costs (e.g., an analogue-to-digital conversion is not required).

The function of light guides may also be achieved by the use of optical fibers of circular cross-section (typically in the range 1.0 to 1.5 mm diameter), rather than of rectangular section. These fibers may be flexible, with one end fixed or attached into a housing, or rigid with one end connected to a pivot.

For an analogue sensor of Figs. 1 to 5, a possible disadvantage of a small diameter optical fiber, compared to a more broad rectangular section, is that the tip diameter could be too small in comparison to the required change in aperture as controlled by the light mask 24. In that case, the planar vane 14 may be preferred.

Another form of digital sensor using small circular section light guides as an encoder, is shown in Figs. 8a and 8b. In this arrangement, two circular section fibers 60 are mounted parallel to each other and mechanically inter-connected by a web section 62 such that they move together when subjected to air flow. The free ends 64 of the light guides 60 are in optical communication with light detectors 66. The free ends receive an interrupted/discretely spaced light pulse as they each sweep over a mask/encoder under the influence of flow in the conduit 12. The encoder is formed by patterns of slots 70 that resemble a grid of alternate opaque/transparent areas on a mask 72. The mask 72 is located between a uniform light source 74 and the free ends 64.

A second mask 80, comprising only one ‘slot’, is fixed to the ends of the free end 64 of each fiber 60, with this single slot aligned to be parallel to the main mask slots 70. The purpose of the second mask 80 is to ensure that only the light from one slot at a time is received by the free ends 64 of the light guides 60.

As in the case for Fig. 6, two output channels, disposed out-of-phase by 90 electrical degrees, are required in order to determine the direction of flow.

Another form of sensor, using polarising film placed between a light source and detector, is shown in Figs. 9a to 9d.

In common with the preceding forms of sensor, the movement of a lightweight vane under the influence of gas flow is optically sensed. Two polarizing films, placed parallel to each other, vary the transmittivity of light according to the relative angle of the polarizing planes of the films. That is, if one film is caused to rotate relative to the other film, whilst the planar surfaces of the films remain parallel, the intensity of light transmitted to a detector on the other side of the films is increased or decreased depending on the initial polarising orientation, and the angle of rotation.

As shown in Figs. 9a and 9b, a flow sensor has one fixed polarising film 90, polarising its surface being parallel to flow in the conduit 12, and a second parallel film 92 in the shape of an arc fixed to the shaft portion of a lightweight vane 96. The vane has a small sail 98 at its free end in order to assist in achieving an appropriate deflection a high flow rates.

The two films are arranged so that the light from an LED 100 (or similar source), mounted on one side of the conduit 12, is directed along a line perpendicular (i.e. in alignment with) to the two polarising films 90, 92 to be detected by a detector 102 on the other side of the conduit 12. The two films 90, 92 act as an optical encoder, in this case by the interaction of the relative orientation of their planes of polarisation. The alignment shown in Figs. 9a and 9b corresponds to zero flow, and is at the mid-point of the moving polarising film 92.

At zero flow, the polarising planes of the two films 90, 92 must be aligned somewhere between 0 and 90° orientation relative to each other. This is necessary in bi-directional flow applications whereby flow direction is determined according to whether the detected light intensity increases for flow in one direction, or decreases for flow in the other direction.

As shown in Figs. 9c and 9d, the maximum and minimum detected light intensities occur at 90°, i.e. when the polarising planes of the two films are either perpendicular or parallel.

The sensor output voltage versus flow characteristic, for the sensor of Figs. 9a-9d, is shown in Fig. 10, where the flow variable was determined using a hot-wire flow meter. The triangle, square and diamond symbols shown represent each of three tests.

Fig. 11 shows the experimentally determined characteristic of Fig. 10 mapped against a theoretical prediction, showing good correlation. The theoretical curve has been determined from the following equations:

$$Q = (A_1 - A_2\Omega)\sqrt{\frac{K_s \cos^{-1}\Omega}{K_s \cos^2\Omega}}$$

where:

A_1: Cross -sectional area of the housing inlet
A_2: Cross-sectional area of pressure drag (the vane)
K_s: Spring constant

$$\Omega = \sqrt{\frac{I}{I_{\max}}}$$

I: Light intensity
K_1 : A system parameter

A general procedure which calibrates the flow transducer, in all its forms whenever the gas blower associated with the conduit, to which the flow transducer is measuring, is started will now be described. This calibration procedure includes the operation of a blower at a specific condition (e.g., pump/motor speed or applied motor voltage), which normally corresponds to a known flow rate (say 150 l/min) at original manufacture conditions. During subsequent start-ups of the blower at any other environmental condition, the indicated flow rate would be compared to the original calibrated flow value, thereby permitting a correction to be made, if necessary.

The corrections that can be made to the measured gas flow include: (i) a constant off-set value, (ii) a percentage of the indicated value, or (iii) a non-linear correction. The correction may be set until the next time the gas blower is started.

The environmental conditions that would normally be expected to affect air density, and consequently the accuracy of the flow meter, includes changes in relative humidity, altitude and ambient temperature. Because of the calibration adjustment, the sensor voltage output/logic value at zero flow is unchanged by variations in the environmental factors described.

Fig. 12 shows a representative schematic diagram for CPAP or assisted ventilation apparatus. A flow generator 100 provides pressurised gas to a patient mask 102 via a flexible tube 104. Within the flow generator is provided a blower, in the form of a motor 110 driving an impeller 112. The motor 110 is speed controlled by a servo 114, and in this way the pressure of gas supplied to the mask can be controlled. A controller 116 provides a controlling signal to the servo 114. The controller also provides output data to operator displays 118, and has an external interface port 120 for programming and diagnostic purposes. Operational signals from switches 122 also are received by the controller 116.

A flow sensor 130, in accordance with any one of the embodiments described above, is located in the outlet conduit 132 extending from the impeller housing. The output flow signal 134 is provided to the controller 116 where, in accordance with a relevant known voltage versus flow characteristic (whether determined experimentally or theoretically, such as in Figs. 10 and 11), is applied to determine the absolute value of flow. This flow information can then be processed in any known manner to control the supply of CPAP or assisted ventilation treatment pressure to a patient.

Although the invention has been described with reference to the specific examples, it will be appreciated by those skilled in the art, that the invention can be embodied in many other forms.

Claims:

1. A measuring device for determining gas flow through a conduit, said device comprising:

a vane arrangement extending into the conduit to be displaceable under the influence of gas flow in the conduit;

a light source arranged to provide a uniform intensity of light over a range of displacement of the vane arrangement;

an optical encoder interposed between the light source and the vane arrangement effective over the range of displacement to encode the light source as a function of displacement of the vane arrangement under the influence of gas flow; and

a light detector, arranged to optically communicate with the encoded light source and provide an output signal related to gas flow.

2. A measuring device as claimed in claim 1, wherein the vane arrangement is attached to the inner wall of the conduit and forms at least one light guide from the free end thereof to the attached end, and said encoder is interposed between the free end (or ends) and the light source so that the encoded light is optically communicated to the light guide (or guides) by the free end (or ends), and further wherein the light detector optically communicates with the light guide (or guides) at the attachment end of the vane arrangement.

3. A measuring device as claimed in claim 2, wherein the encoder comprises a mask extending of its length over the range of displacement, being configured to transmit a range of light intensities as a function of position along its length.

4. A measuring device as claimed in claim 3, wherein the mask is tapered of its length.

5. A measuring device as claimed in claim 4, wherein the mask has a double taper to form an arrowhead shaped aperture.

6. A measuring device as claimed in claim 2, wherein the vane arrangement has two light guides, and the encoder comprises two rows of regularly spaced discrete light sources aligned with the free end of the respective light guide, and further wherein the light detector provides two output signals, one for each respective light guide.

7. A measuring device as claimed in claim 6, wherein the discrete light sources are formed by slots made in an opaque material covering a sheet of light transmission material.

8. A measuring device as claimed in any one of the preceding claims, wherein the vane has a smaller gas impinging dimension in a portion proximate the attachment end than the free end.

9. A measuring device as claimed in claim 1, wherein the vane arrangement carries a first polarising element, and the first polarising element and a second, fixed polarising element form the encoder, and further wherein the light source, the first and second polarising elements and the light detector are in optical alignment, the planes of polarisation of the respective first and second polarising elements interacting as a function of displacement of the vane element to result in variable optical transmitivity.

10. A measuring device as claimed in claim 9, wherein said vane arrangement is formed as a pivoting shaft to which is attached the first polarising sheet, and a distally located vane element.

11. A measuring device as claimed in either one of claim 9 or claim 10, wherein the first polarising element is arcuately shaped.

12. CPAP or assisted ventilation apparatus comprising:

a blower to produce pressurised breathable gas;

a gas supply conduit;

a device to deliver said gas to a patient's airways;

a controller having control over operation of the blower; and

a flow measuring device as defined in any one of the preceding claims, wherein the output gas flow signal is provided to the controller as a control variable therefor.

13. A method for determining gas flow through a conduit, comprising the steps of:

providing a uniform light source;

encoding the light source in a manner that is a function of a displacement of a vane arrangement located within the conduit and under the influence of gas flow; and

detecting the encoded light and producing an output signal related to gas flow.

DATED this Eleventh Day of June 1999

ResMed Limited

Patent Attorneys for the Applicant

SPRUSON & FERGUSON

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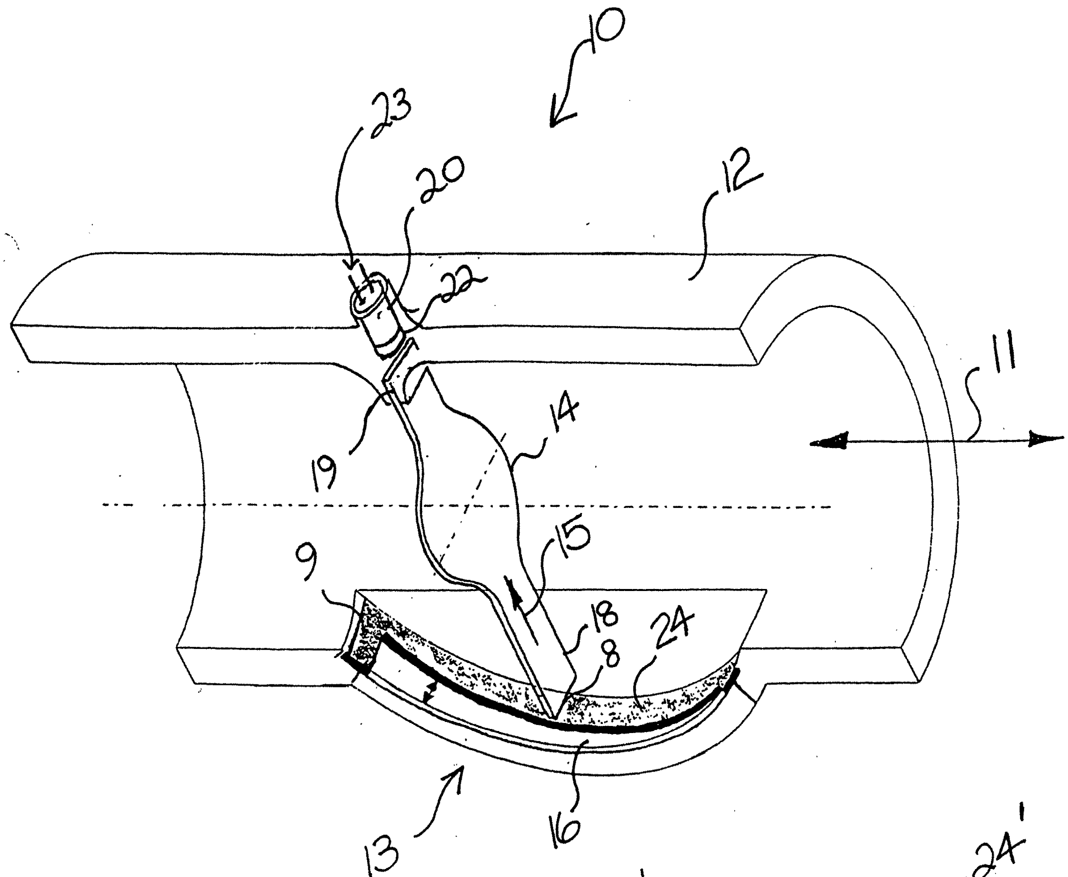


FIG. 1

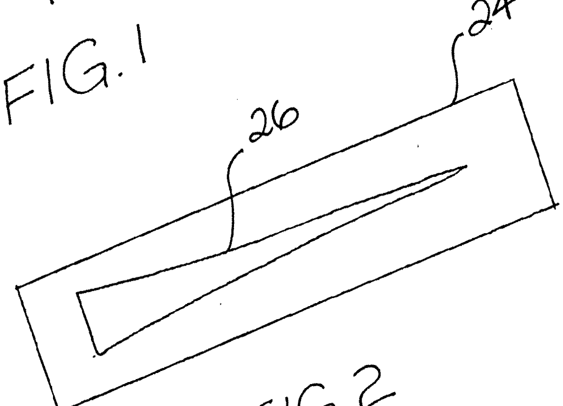


FIG. 2

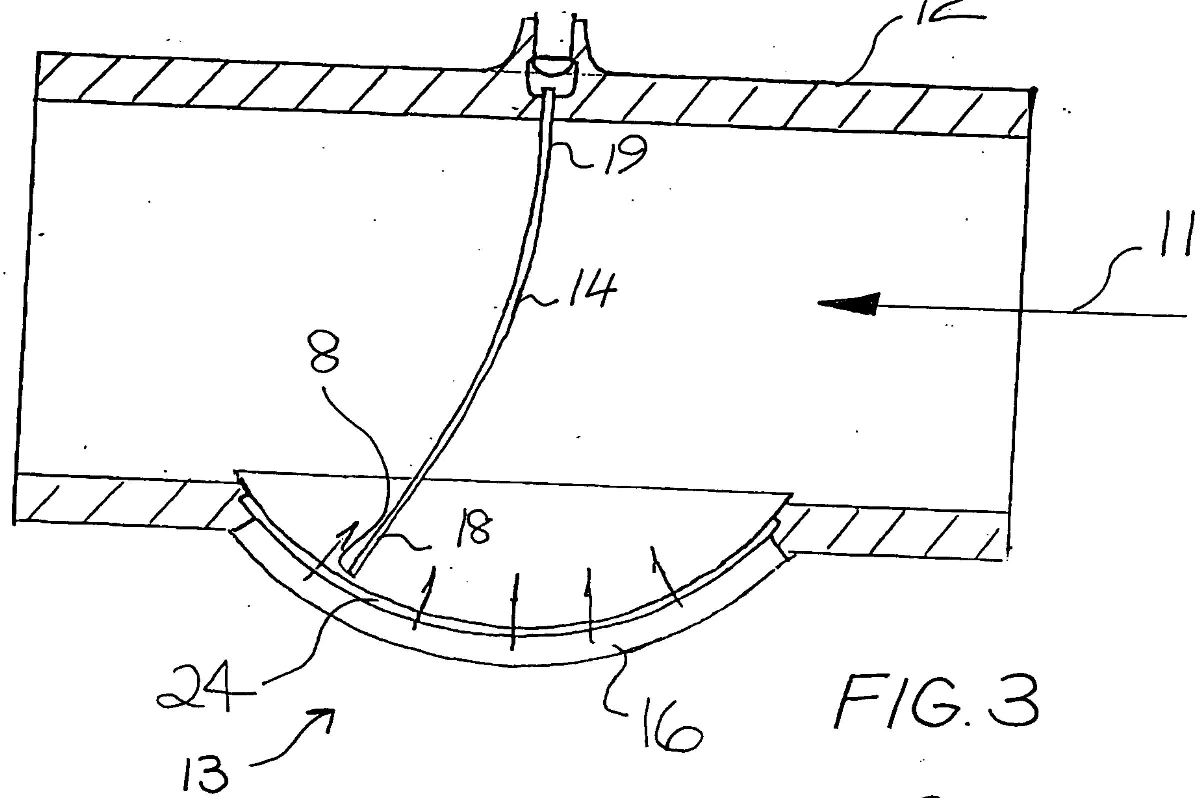


FIG. 3

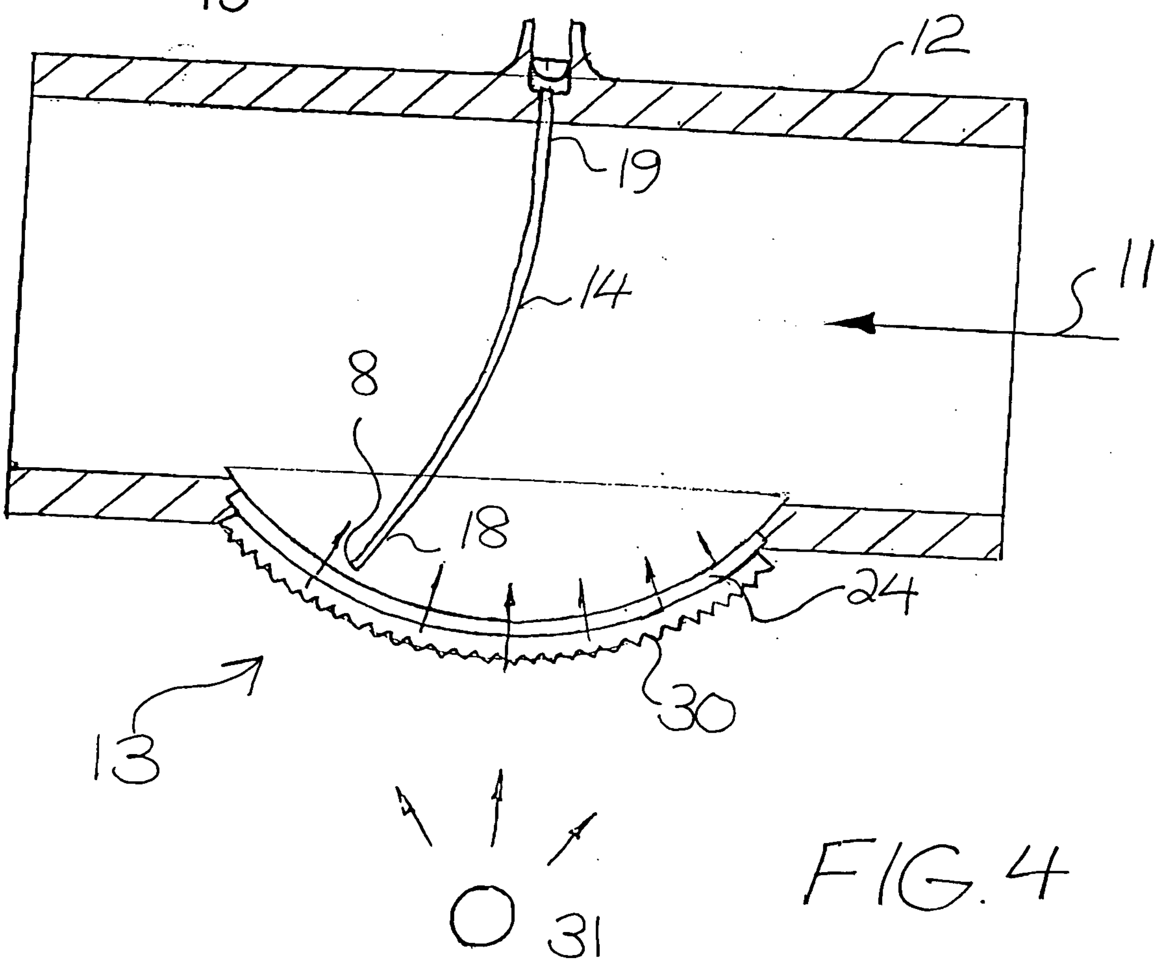


FIG. 4

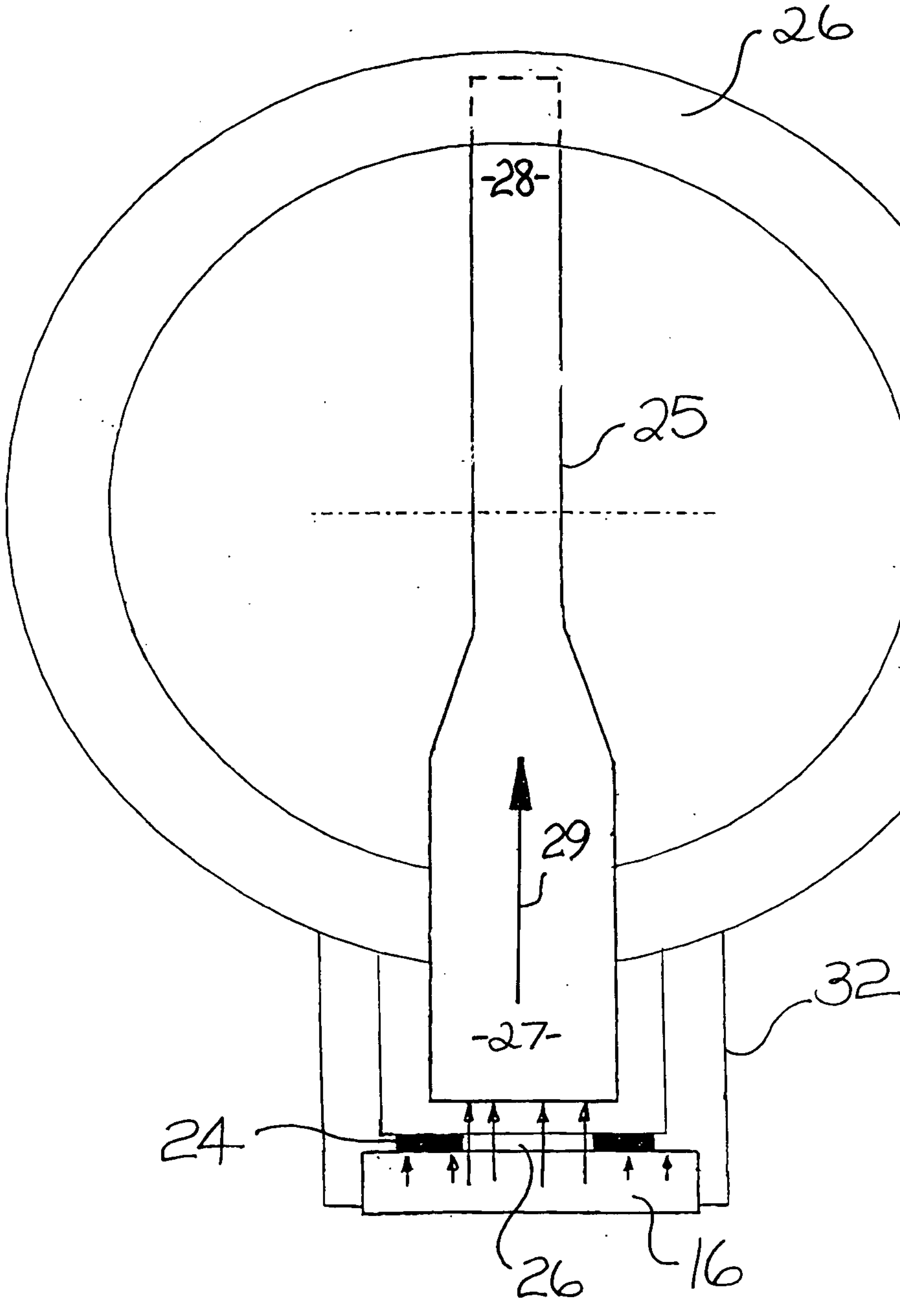


FIG. 5

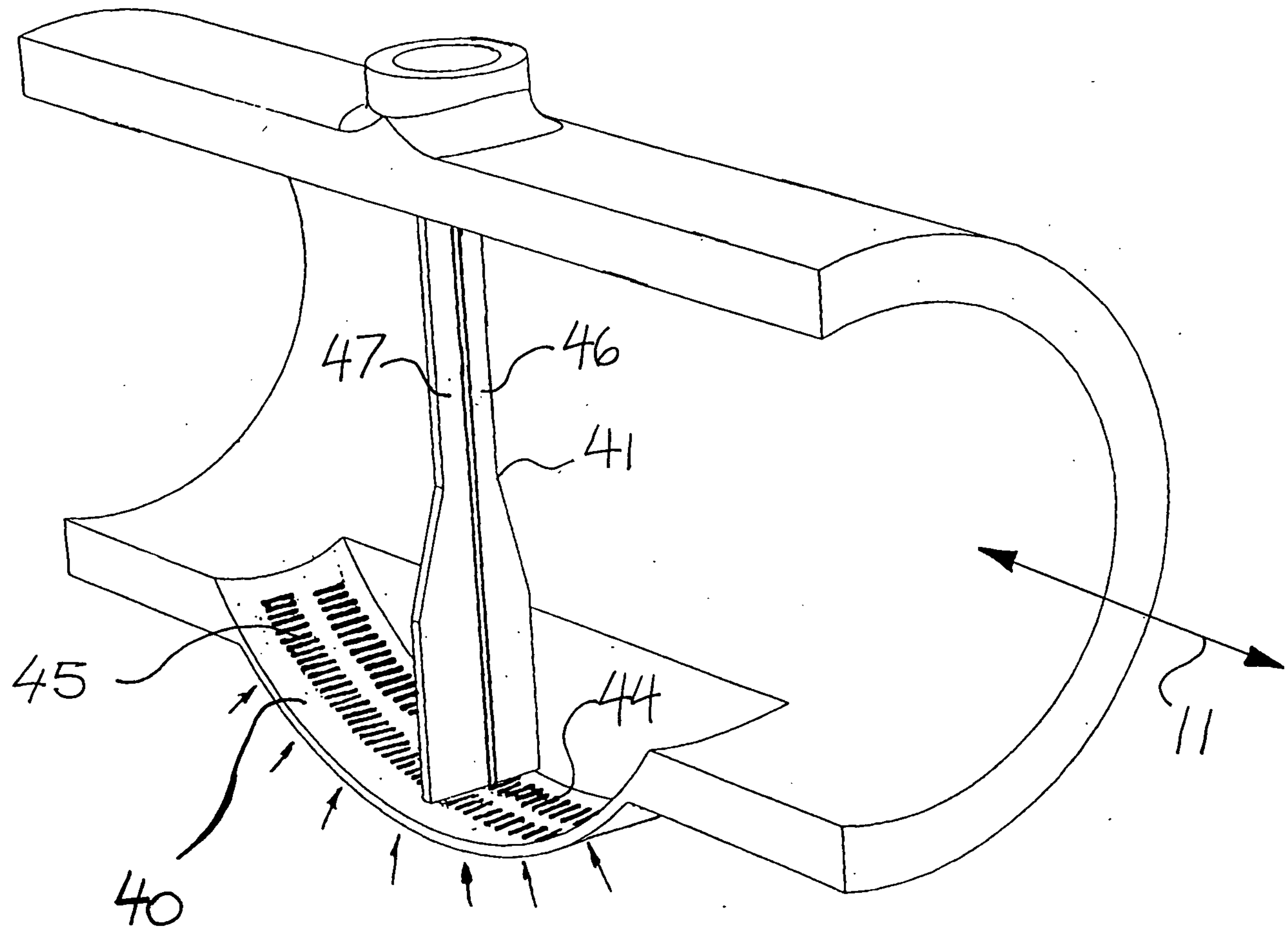


FIG. 6

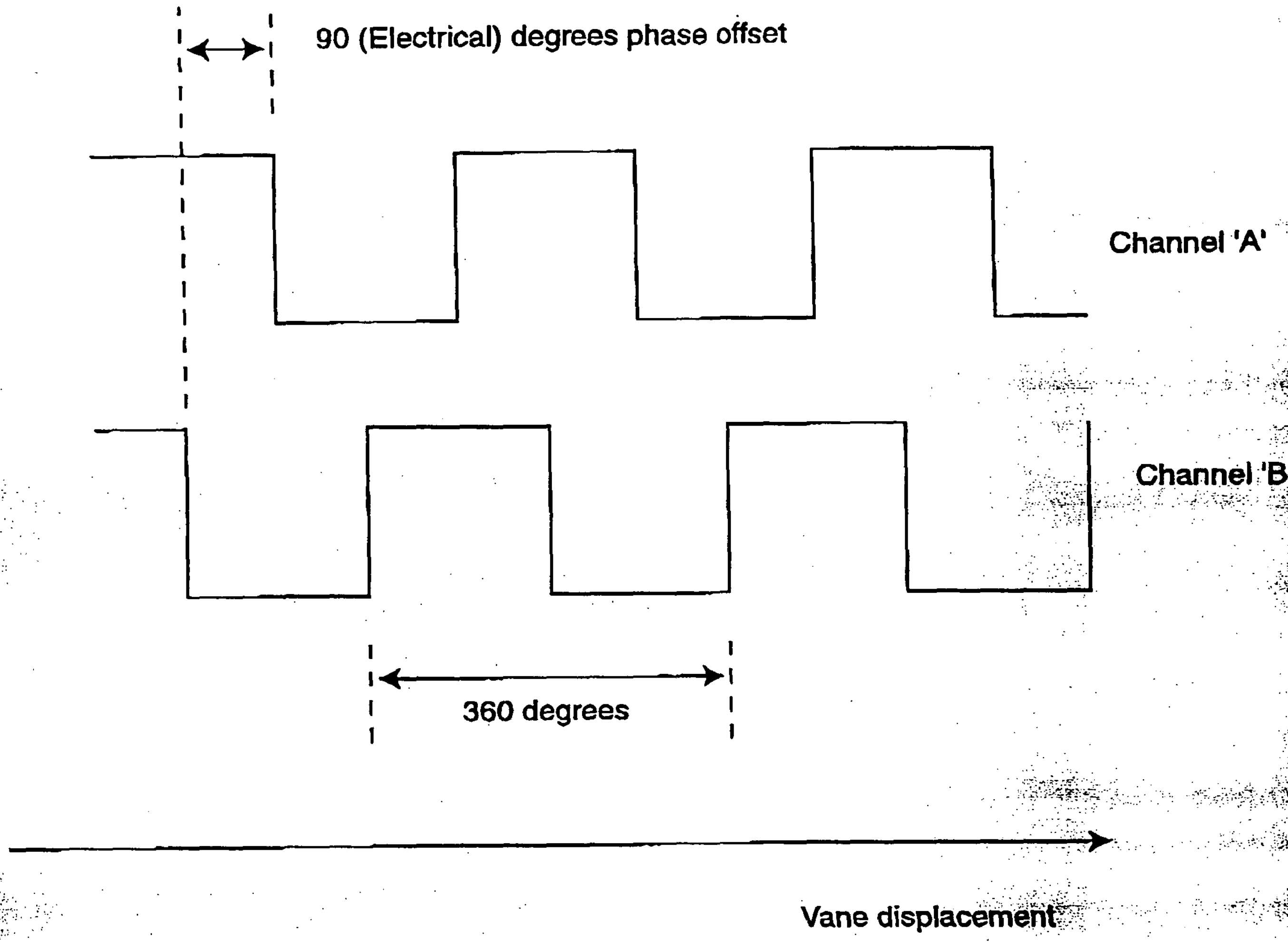

90 (Electrical) degrees phase offset
Channel 'A'
Channel 'B'
360 degrees
Vane displacement

Figure 7

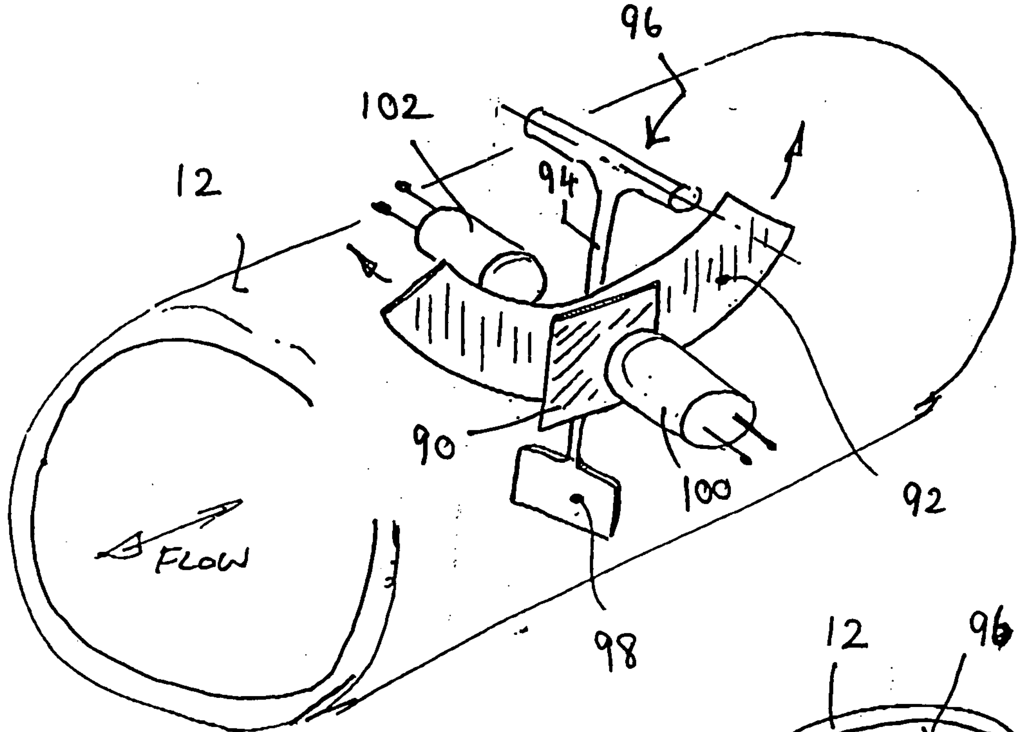
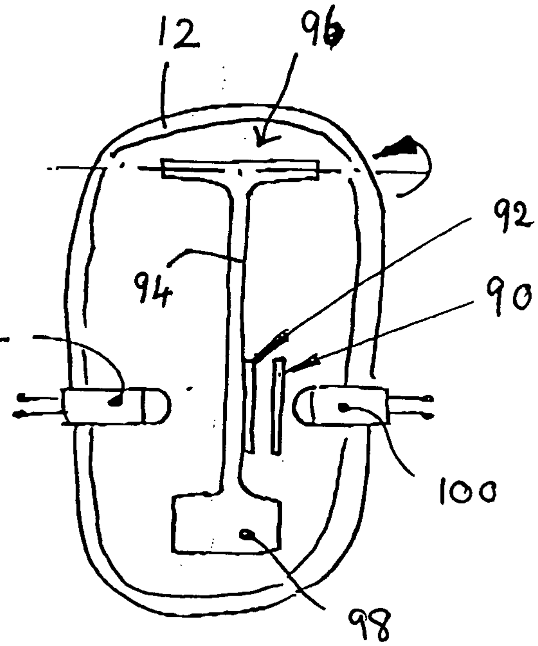


Fig. 9a

Fig. 9b



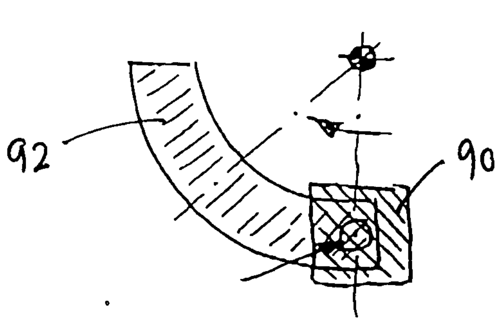


Fig. 9c

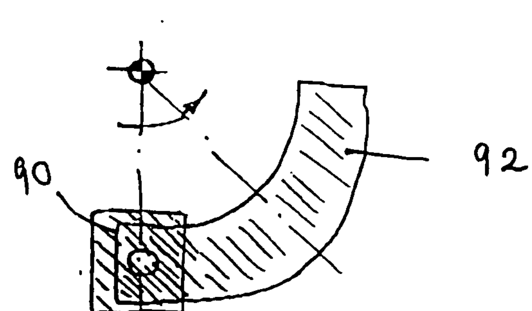


Fig. 9d

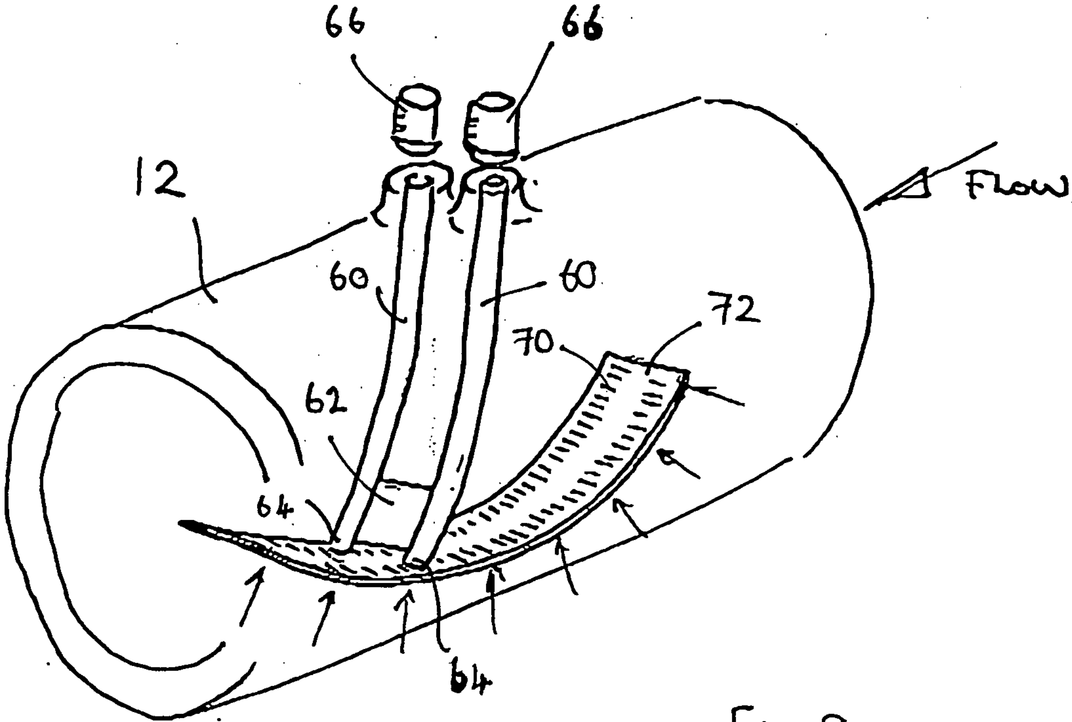
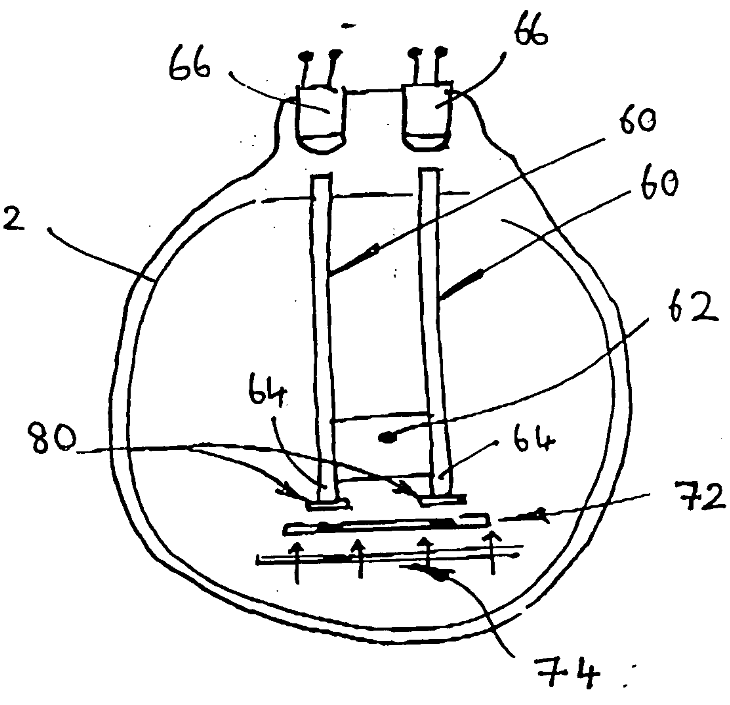


Fig. 8a

Fig. 8b



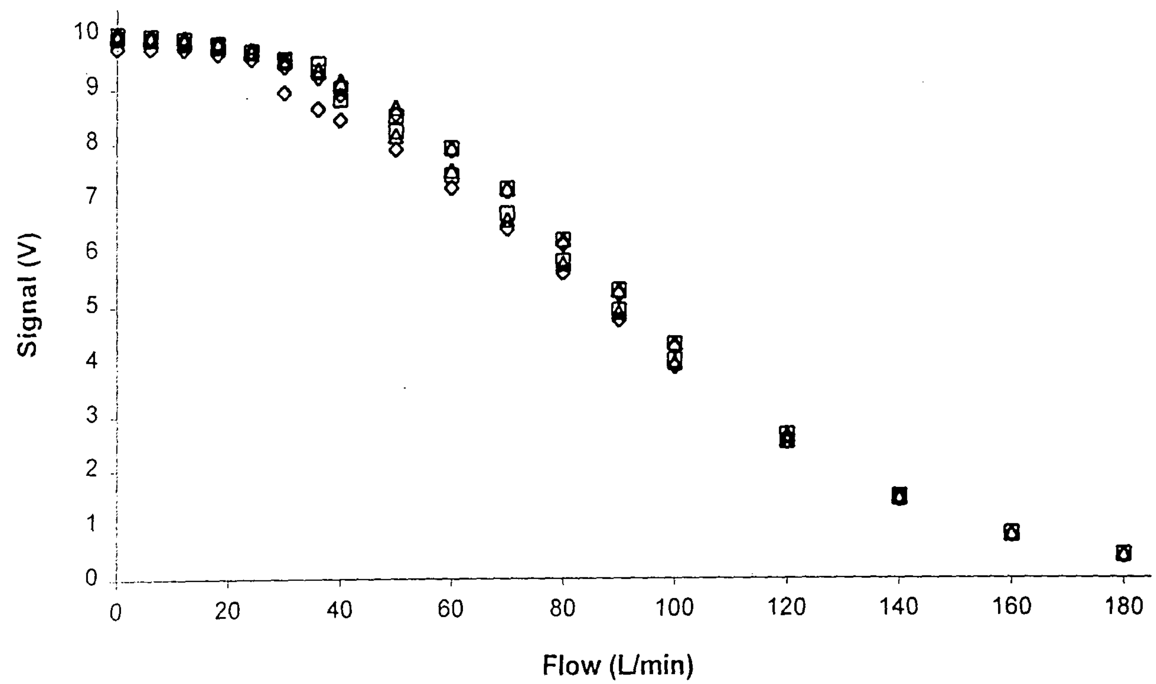

Signal (V)
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
180
Flow (L/min)

Fig. 10